Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

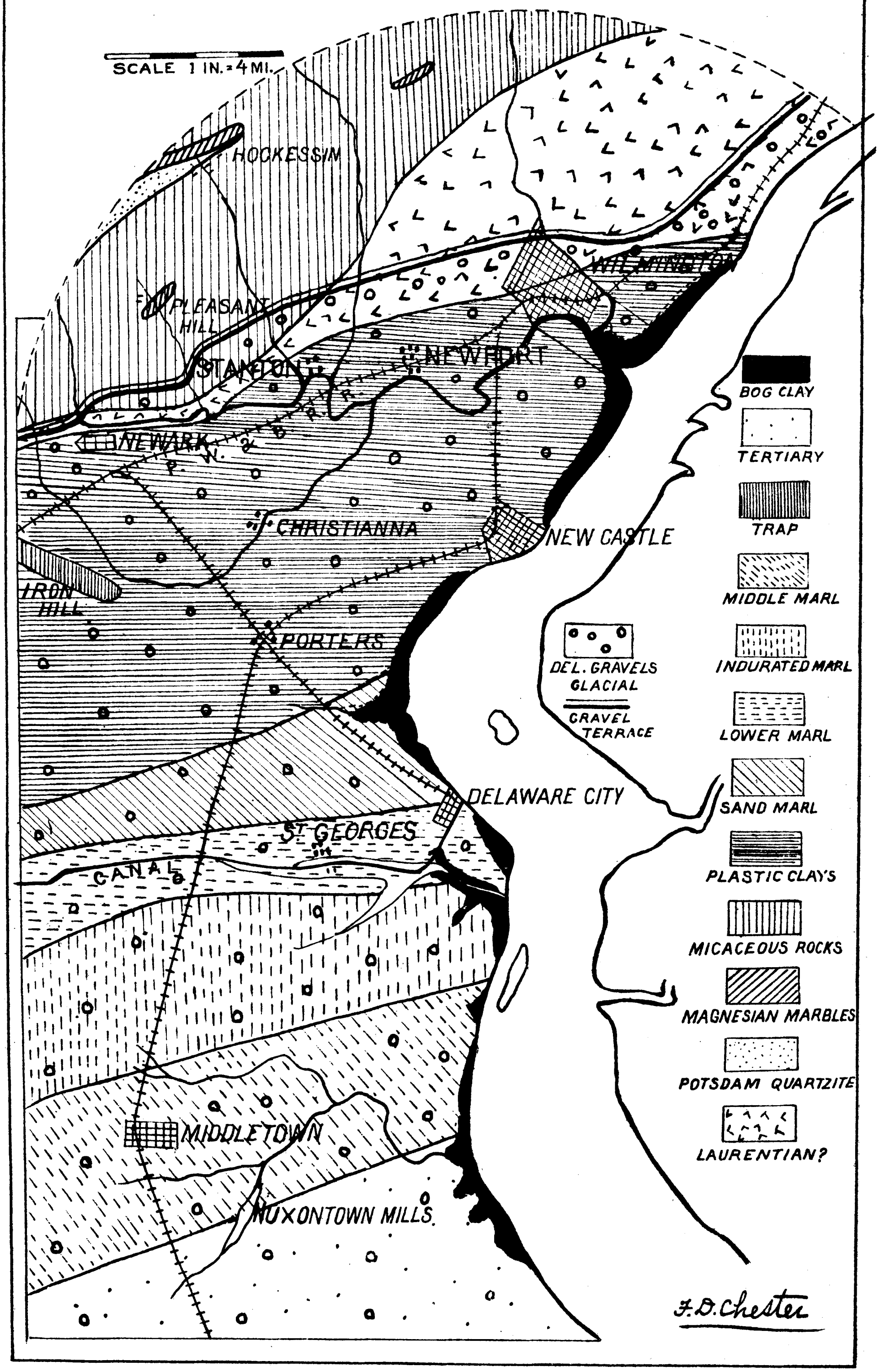
Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

GEOLOGICAL MAP OF NORTHERN DELAWARE.



PRELIMINARY NOTES ON THE GEOLOGY OF DELAWARE—LAURENTIAN, PALÆOZOIC AND CRETACEOUS AREAS.

BY FREDERICK D. CHESTER.

INTRODUCTION.

During the years 1837 and 1838, Professor James C. Booth, in accordance with an act of the State Legislature, made a geological survey of Delaware, the results of which were published in a report that appeared in 1841. This old memoir is of great value, both from the accuracy of the author's observations and his minute attention to detail; I cannot, therefore, expect to supplant it, my aim being an entirely different one, *i. e.*, to so completely reconstruct our geology as to bring it into sympathy with the results of adjacent States. Professor Booth's great and only fault as a geologist lay in his entire indifference to stratigraphical order; and his classification of deposits according to mineralogical and physical characters, leaves one in utter confusion.

My main object, therefore, is to endeavor to undo the tangles which Professor Booth has unconsciously made, by stating the facts in the briefest and clearest manner possible.

The results, as embodied in the following paper, are preliminary to what is hoped will be a full report upon the State.

GEOLOGICAL OUTLINE.

The formations represented within the bounds of the State are Laurentian (?), Cambro-Silurian, Silurian-Devonian (?), Cretaceous, Tertiary and Quarternary. The relations and positions of the several divisions of the chronological scale can be best represented by the accompanying table (I), also the thickness of each formation. Column 2, with which the Delaware series is compared, is constructed according to what seem the best results, combining home and foreign equivalents. The accompanying map (Pl. V) is drawn upon a scale of four miles to the inch, and is sufficiently large to show all necessary details. A word is here necessary in regard to the boundaries as shown by the map. The lenticular areas which indicate the magnesian marble, can only serve to represent the position of outcrops. Owing to the fact that these calcareous deposits are entirely covered by the micaceous rocks, surface indications offer no means of determining the entire area covered by the former.

I.

Periods.	General Series.	Delaware Series.
Quarternary.	Modern.	Bog Clay or Alluvium.
	Post-Glacial. Glacial.	Delaware Gravels and Estuary Sands—10–40′.
Tertiary.	Pliocene.	Blue Clay—3–10′. Glass Sand.—40′.
	Miocene.	White, Potters' Clay—10–20′.
	Eocene.	
Cretaceous.	Upper.	Middle Marl—139′.
		Indurated Marl—149′.
		Lower Marl Bed—60′.
	Middle.	Sand Marl—90′.
	Lower. (Wealden.)	Plastic Clays—250′.
		Mica Schists and Gneisses.
Cambro-Silurian.	Calciferous. Potsdam.	Magnesian Marbles. Quartzite.
Laurentian (?)	Laurentian (?)	Syenitic Rocks.

Owing also to the fewness of the outcrops of the several divisions of the Cretaceous, the boundaries had to be drawn from such data as were accessible, which were in some cases abundant, and in others entirely absent. Sufficient is known, however, to make the writer confident of their general accuracy; while the missing links of knowledge could only be supplied by expensive borings.

The Laurentian.—To this belongs the belt of hornblendic rocks above the line of the Pennsylvania R. R., which to the west is narrow but which rapidly broadens to the east, as it extends into Delaware county, Pa., and contracting again to a narrow neck at Chester Creek, there connects with another irregular area occupying all the northwestern portion of Delaware county. This area connects with still another to the north, and to the east of West Chester. This rock is a dark hornblendic gneiss or amphibolite schist, dipping usually to the northwest, rarely in the opposite direction. With it is associated a grayish to bluish gray rock, usually finely crystalline, which has been designated as diorite and syenitic granite by the Pennsylvania geologists. Owing to the absence of petrographical facts concerning this rock, however, nothing definite can be said concerning it. It shades by indistinct degrees into the amphibolite schists, the two varieties probably forming the same eruptive series.

The Cambro-Silurian.—This formation, so largely developed through the counties of southeastern Pennsylvania, has one area in the northwestern part of Delaware, and two smaller exposures. In the northwestern area, a coarse quartzitic rock is found to underlie a highly crystalline magnesian marble. These, as we shall more clearly perceive further on, must be referred respectively to the Potsdam and Calciferous, the latter of which is equivalent to the Lower Magnesian limestone of the West.

The Mica Schists and Gneisses.—To the north of the belt of Laurentian gneisses, and resting upon the latter, is a series of mica schists and granitic gneisses, with which are associated bedded granites, serpentine, and hornblende rocks. They have commonly been referred to the *Mont-Alban*, which, together with the older hornblendic rocks, were called *Azoic*, the two forming a part of the southern gneiss area as known by the Pennsylvania geologists. It will be my aim, shortly, to show that the hornblendic rocks and mica schists do not make two successive formations, within the Azoic, but that, while the former is either Laurentian or Huronian, the latter must be placed above the Trenton, and possibly above the Hudson River, slates. Their exact position in the Palæozoic scale, however, will probably never be determined, owing to the complete absence of fossiliferous remains, due to the extreme metamorphism. The rocks have been subjected to great contortion, the strata having been pressed either into close folds, or into broad or contracted anticlinal or synclinal flexures.

The Cretaceous.—Resting upon the eroded edge of the Azoic rocks are successive series of plastic clays, sand marls and greensand, which form quite uniform strata, dipping at a low angle to the southeast. This belt, having a width of 18 miles, extends from the hills to the latitude of Noxontown mill pond, just south of Middletown.

The Tertiary.—The Cretaceous is succeeded by a stratum of white or lead-colored clay, having a thickness of 10 to 20 feet. This continues as far south as Murderkill Creek, and from fossiliferous evidence, must be referred to the Miocene.

South of Murderkill Creek, the Miocene is succeeded by 3 to 10 feet of light or dark blue clay, beneath which is a uniform stratum of fine glass sand, of at least 40 feet in thickness. That all the State south of Murderkill is later Pliocene, I shall endeavor to prove in a future paper upon the younger formation.

All the beds of the Tertiary lie in a nearly horizontal position, dipping at a still lower angle than the Cretaceous, and probably unconformable to the same.

The Quarternary.—Covering most of the foregoing formations, and reaching up the flanks of the Azoic hills to the height of 200 feet or more above tide, is a layer of sand and gravel, which to the north is of a coarse, red nature, and to the south is fine and white. They are called the Delaware Gravels and Estuary Sands, respectively. Along the river and bay shores is also the belt of bog-clay, which is modern, and of more recent origin than the gravels. Also upon the summits of the highest hills in the State are solitary patches of gravel which are evidently older than the continuous stratum to the south. This high-level gravel, in the absence of proper data, has been problematically referred to the Tertiary, and is known as *Bryn Mawr* gravel.

THE CRYSTALLINE ROCKS.

Geographical Position.—Generally speaking, the southern line of the Azoic rocks is the limit of the highlands, but in certain places they extend well into more level regions. Beginning with a point upon the Maryland boundary, a little north of where the latter is cut by the Mason and Dixon line, the limit of the rocks runs in a northeast direction, cutting through the western end of Newark, and following the northern boundary of the town.

Thence it runs close to the south shore of White Clay Creek to a distance of two miles beyond Roseville, where it makes an abrupt bend to the north, until at Stanton the rocks cease to be found. A mile back of the railroad station, they again appear, continuing to a point about a mile back of Newport, where their course turns slightly to the southeast, crossing the Wilmington turnpike just before it is intersected by the Wilmington Northern R. R., thence it follows the turnpike through the southern half of the city, keeping just north of the Pennsylvania R. R., to a point south of Bellevue, where the line cuts the river. From there the Delaware River marks the southern boundary. The area as above indicated may be divided into two pretty distinct belts: (1) the southern belt of hornblendic rocks, and (2) the northern belt of micaceous rocks, with which are associated interstratified beds of coarse-grained orthoclase granite, feldspar, quartz and quartzite.

The boundary line between these two belts can be traced very accurately, and is found to correspond pretty closely with the lines of strike. Beginning with the western boundary of the State, the line follows approximately the course previously traced out, but one-half a mile to the north of the same. It continues thus to a point south of Milltown, when an abrupt turn to the northeast is taken, the line crossing the Brandywine only a few miles from the head of the State. It is owing to the northerly course of this line, as compared with the southern limit of the Azoic area, that the northeastern portion of the State is covered more largely with the hornblende, and the northwestern with the micaceous rocks.

THE LITHOLOGY OF THE CRYSTALLINE ROCKS.

The rocks which cover the crystalline area may be classed as follows:—

Micaceous	Granite, Granitic gneiss, Mica schist.
Hornblendic	Amphibolite schist, Blue to gray trap.
Calcareous	Marble, Saccharoidal limestone.
Serpentine.	
Quartzite.	
Vitreous quartz.	

Granite.—This rock, as known in the State, is divided into two classes: (1) that which forms intrusive beds, being a coarsely crystalline orthoclase granite, and (2) that which is nothing more than a highly metamorphosed granitic gneiss, or mica schist, it being a very compact, fine-grained rock. The former variety may be described as an intimate mixture of flesh-colored orthoclase, quartz and muscovite mica, with which are often associated albite and biotite. It occurs as veins, usually bedded, which vary in width from 6 inches to 25 feet, and which, though often continuing in length for several miles, are known to pinch out entirely. The great difference in lithological character between the enclosing rocks and these beds would imply that the latter are veins of plastic injection from aqueo-igneous fusion. That the intrusion of the semi-molten magma was subsequent to the uplifting and crystallizing of the enclosing rocks, is proven by the fact that the latter have, in the vicinity of such veins, suffered considerable disturbance and undue metamorphism at the planes of contact with the intruded mass. The granite is often so highly feldspathic as to be worked exclusively for this mineral, and when the upper portions of such veins are greatly decomposed, diggings have in a few cases been made for kaolin.

One of the most noticeable of these veins of coarse granite is found to cut across the road leading up the Brandywine, about one and a half miles from the head of the State. A large quarry has been opened in this vicinity, where the rock has been worked for feldspar. The vein is not less than 20 feet wide, on the one side of which is a highly metamorphosed mica schist, and on the other hornblendic gneiss. The rock is a mixture of red orthoclase, albite, blue quartz, and muscovite, the crystals being sometimes so large that perfect specimens of feldspar several inches square, can be obtained. Large hexagonal plates of mica, many of them 6 inches across, are also found in abundance. The same feldspar is worked three miles to the northeast, probably from the same vein, as near as could be determined; while in the other direction the intrusive mass seems to lose itself.

Another equally wide vein cuts across the Newark and Avondale R. R., at Tweed's mill, two miles north of Newark. A faulting plane cuts through this intrusive bed, possibly due to its disturbing action.

The same rock is found to continue two miles and a half to the northeast, outcropping upon the run to the south of Pleasant Hill P. O. Many other instances of granite veins might be cited, but with nothing new regarding them. All of the large veins mentioned above are exclusive of the smaller seams, which vary in width from a few inches to a foot, and which are liable to be found anywhere, and frequently, within the micaceous belt.

The second class of granite—a highly changed gneiss or schist—is a fine-grained rock containing quartz, plagioclase and biotite, with the quartz subject to considerable variation.

It occurs as massive beds, the planes of the stratification being so completely obliterated that the rock resembles a true trap. That it is not trappean, however, is shown by the fact that it is seen to run, by indistinct degrees, into mica schist. Such rocks are usually much broken up, thus testifying to an undue mechanical activity, itself the cause of the extreme metamorphism.

Granitic Gneiss and Mica Schist.—These two species represent the extremes of variation in what is the characteristic rock of the micaceous belt, which has gone by the generally applicable name of gneiss. These two rocks so merge into each other that specific designation is often difficult. The typical mica schist may be described as a very schistose biotite rock, usually highly garnetiferous, and containing a variable proportion of quartz. Sometimes this highly micaceous rock contains a very small proportion of feldspar, which can often only be seen as a kaoline substance in the decomposed product; and if the absence of feldspar be characteristic of mica schist, then with the presence of feldspar the true schists begin to run into gneiss.

Hornblende Rocks.—The hornblende rocks, as a class, may be divided into the basic and acidic, or into those rocks of which the predominating constituent is either hornblende or feldspar. To the former belong the dark varieties of amphibolite schist and syenitic gneiss, and to the latter belongs the light, highly acidic bluish gray trap so characteristic of the northeastern part of the State. Between these two extremes there is every shade of gradation, showing some petrographical relation between them. The dark varieties of amphibolite schist vary in color from a blue to a dull black, from coarsely crystalline to compact. The predominating element is hornblende, with which is associated a small proportion of plagioclase, and sometimes blue quartz. This rock, which shows a more or less eminent lamination, is found to merge into a massive rock of the same composition. When the proportion of hornblende increases, it becomes so great as to make up, apparently, the entire composition, in which case the syenitic gneiss runs into the hornblende schist or into massive hornblende rock. The bluish gray trap may be described as follows: in color it varies from a light to a dark bluish gray; in texture, from a coarsely crystalline to one fine-grained, homogeneous and trappean in character.

Lithologically, the rock is composed of plagioclase, feldspar and hornblende, with frequently a small proportion of blue quartz and biotite.

Massive hypersthene has often been found in fine orthorhombic crystals, entirely replacing the hornblende, and is associated with a plagioclase showing the most eminent striation. Thus, from microscopical examination, the rock seems to range from a *quartz diorite* to a true *hyperite*, although no true knowledge of the rock can be had until a thorough microscopical study is made. Professor G. H. Williams,[1] of Johns Hopkins University, has proven a similar rock, in the vicinity of Baltimore, to be a *hypersthene gabbro*, which also runs by indistinct stages into a true *amphibolite schist*. He has also shown that the *amphibolite* is the result of a paragenesis taking place in the *gabbro*, the hypersthene and pyroxene found in the latter being altered to hornblende, and thus producing the gradual passage of gabbro into amphibolite. Whether some such alteration as this can account for the passage of the bluish gray trap into amphibolite schist is quite within the range of possibility. This question has already become a subject of investigation by the writer, and it is hoped that much light will be thrown upon it.

Calcareous Rocks.—To this class belong those rocks generally called crystalline limestone, of which there are two varieties, namely, saccharoidal limestone and marble. They are found at three known localities, one near Pleasant Hill, one at Hockessin and another near Centreville, both varieties occurring together.

The marble may be described as very coarsely crystalline. It is very compact in texture, of superior hardness, and is always heavily and closely bedded. The variety called saccharoidal limestone is more granular and extremely friable. It is also less pure, being often colored by oxide of iron or organic matter, and is much more thinly bedded, the thinner seams being interstratified with the heavily bedded marble.

---

[1] Am. Jour. of Sci., October, 1884, and Johns Hopkins Univ. Circular, April, 1884.

Serpentine.—About six miles northeast of Wilmington a huge dike of serpentine runs with the micaceous schists. Its length can be traced by outcropping boulders for a distance of a mile, with a width of a quarter of a mile. The rock varies from one tough and massive to one soft and highly decomposed, with which are associated talc and magnesite.

Vitreous Quartz and Quartzite.—The former rock occurs as regular thin or massive seams interstratified with the micaceous rocks. It varies from a glassy colorless variety to one of milky and opaque whiteness. The quartzite, which is found in the northwest corner of the State, underlying the limestone, is probably of Potsdam age. It is a very coarse quartzite rock, which contains, frequently, crystals of *tourmaline*, *fibrolite* and *actinolite.*

STRUCTURAL RELATIONS OF THE CRYSTALLINE ROCKS.

Strike and Dip.—The rocks of this formation, except in a very few cases, are all stratified with variations of bedding, from that as thin as slate in the mica schists to that so heavy as to resemble massive trap intrusions. Both strike and dip are subject to great variation. A dip to the southeast for a long distance, with an opposite dip along a section only two miles and a half to the northeast, can be accounted for only by supposing an unequal thrust from the direction of the contorting force. In fact, out of five different sections made across the Azoic belt at various points of its length, no two showed the same arrangement of strata—from which we conclude that the thrusting force must have acted very unequally along the entire length of the belt, sometimes merely tilting the strata; again, standing them on edge, and yet again, completely overturning them; in some places pressing them into close folds for a part or the entire length of the section, in others leaving gentle or abrupt anticlinal and synclinal folds.

Both strike and dip are also found to be subject to variations from the disturbing action of granitic intrusions. At Dixon's spar quarry the change is from N. 55° E. to N. 22° E. At Pleasant Hill a granitic vein cuts through the limestone, which causes a disturbance from N. 55° E. to N. 10° E. Excluding cases of local distortion, however, the crystalline rocks range in strike between N. 45° E. to N. 60° E., and in dip from nearly vertical to nearly horizontal.

Dikes.—We have already spoken of the granite and serpentine as intrusive, forming in certain cases true beds, and again, showing genuine vein structure with numerous branchings. Regarding the structural relations of the bluish gray trap, there are as yet some doubts. The geologists of the Second Pennsylvania Survey have spoken of it as forming massive trap intrusions between hornblende gneiss—of which the latter is metamorphic.

This theory, I am inclined to think, will prove to be a mistaken one. In Delaware, as we have said, the gray acided rock runs by indistinct gradations into true amphibolite schist, the many stages of variations being sometimes witnessed in a single quarry, without the slightest structural distinctions. Seams of the gray trap have been seen running through the black hornblende gneiss, but without the least signs of intrusion. That the bluish gray trap may occupy irregular patches more or less lenticular, is no doubt true, but the latter can in no sense be regarded as forming dikes between a metamorphic schist; on the other hand, all the rocks of the hornblendic belt, from the most acidic gray trap to the true amphibolite schist, belong to a single series of eruptive rocks, having wide lithological variations. That these variations may be the result of a subsequent paramorphosis taking place in the bluish gray trap is quite possible; it is therefore to be hoped that present petrographical studies of the hornblendic rocks of the State will throw more light on this important question.

Contortion of Strata.—The crystalline rocks offer the most complicated and striking examples of contortion, presenting nothing, however, which is not characteristic of all metamorphic areas. Close folding is the form generally seen, the line of bedding being either straight, gently or violently contorted. Abrupt anticlinal and synclinal folding is also common, these complex folds being, however, very irregular and much twisted.

Age and Stratigraphical Order.—The crystalline rocks may be divided into four groups, which have a fixed stratigraphical relation to each other, namely, the hornblendic, the micaceous, the calcareous and the quartzitic.

The normal order of arrangement of these strata, and thereby their relative age, is a point upon which there has been much difference of opinion, owing to the confusing arrangement of the strata throughout some of the counties of southeastern Pennsylvania. Notwithstanding such difficulties, the geologists who have discarded broad generalizations, and devoted themselves to the study of local details, find the way gradually opening to a better understanding of the truth; and the early presumption that the mica schists and gneisses are of Palæozoic age, is rapidly becoming a matter of general acceptation. The latest results of geological study in Pennsylvania, together with the observations of the writer throughout Northern Delaware, tend to show quite conclusively that the crystalline rocks represent the following ages: (1) The Laurentian (?) including the rocks of the hornblendic belt; (2) the Potsdam, to which the quartzitic and sand rocks belong; (3) the Calciferous, including the magnesian marbles, and (4) the age of the mica schists, which must be placed somewhere above the Trenton, and, according to Mr. Charles E. Hall, above the Hudson River, slates. With these points in view, we shall proceed with the demonstration.

The Laurentian (?)—The so-called Laurentian area of Delaware is but a continuation of identical areas in southeastern Pennsylvania, within the Philadelphia belt, which, according to Mr. Hall, are three in number, each connected with the other by a narrow neck, and each situated successively to the northeast. The southernmost of these areas is of lenticular shape, reaching from Chester Creek, and spreading out over the southern part of Delaware County, whence it extends into the State of Delaware, as shown upon the map. Northeast of this patch, and to the northwest of Media, is another area of irregular form, while a third—a long east and west belt—runs from West Chester, south of Conshohocken, eastward to the Delaware River, near Trenton. Thus the Delaware Laurentian forms the southernmost tongue of the one Laurentian area of the Philadelphia belt, the upper portion of which has been for a long time known as the *Third Belt* of Rogers. As regards the age of the *Third Belt*, Mr. Hall says, "The rocks of the *Third Belt* are identical with the granitoid and syenitic rocks of the Welsh Mountain, north of the Chester County limestone valley. These rocks of the Welsh Mountain are similar in all respects to the crystalline rocks extending into

Pennsylvania from New Jersey. In New Jersey they are identified as belonging to the Laurentian."

With these points in view, I have followed Mr. Hall, and placed the syenitic rocks of Delaware in the Laurentian, although I feel that it is, at best, but a problematical designation. Any positive declaration upon this point would be premature, until a more thorough structural and petrographical study has been finished, together with a comparison of results from diverse localities. Throughout southeastern Pennsylvania the hornblendic rocks are always stratigraphically the lowest, and such is the case in northern Delaware.

The general dip of the syenitic rocks, upon the flanks of which rest the strata of the micaceous belt, is, in the latter locality, to the northwest. In the western part of the State, however, the hornblendic rocks have experienced an overthrow, whereby they dip to the southeast, in which case the hornblendic rocks are apparently the younger. This peculiarity need not, however, be misleading as to true stratigraphical order. Putting aside all questions of position of strata, one must note the decidedly primitive aspect of these rocks, which, in lithological characters, are identical with the rocks of more northern portions of the Laurentian area.

The Potsdam.—In the northwestern part of Mill Creek Hundred, a triangular area of Potsdam sandstone is seen upon the map, which, rising from beneath a patch of Bryn Mawr gravel, extends into Pennsylvania, and is best exposed beyond the State line. At Nivin's limestone quarry, a mass of quartzite forms what is clearly an anticlinal fold, over which is a corresponding anticlinal of magnesian limestone. The anticlinal structure of the quartzite is further shown at a few other points, where dips both to the northwest and southeast are noted.

The Calciferous.—Mr. Hall divided the limestone of southeastern Pennsylvania into two groups, namely, the Calciferous magnesia limestones and marbles, and the possible Trenton limestones and slates, the former comprising the rocks of the Chester County limestone valley, and several outlying troughs to the south, the latter those alternations of slate and limestone which form the outer border of the Calciferous belt.

The limestone areas of Delaware belong to the lower of the above groups, or to the Calciferous of Mr. Hall, the equivalent of the Lower Magnesian limestone of the West. The magnesian marble which outcrops beyond the State line, at Nivin's, runs into Delaware, and appears at the surface in the Jackson quarry at Hockessin. Here the rock forms a clearly defined anticlinal fold. The bending, both to the northwest and southeast, being observed within the cutting. The limestone is overlaid by the mica schists which, to the north of the pit, dip to the northwest, and to the south, southeast, forming an anticlinal fold capping the limestone.

To the southeast of Centreville, the limestone occupies the same stratigraphical position as in the case just mentioned. At Pleasant Hill the bending of the schists over a saddle of limestone is beautifully shown in the quarry cutting, furnishing clear proof as to the superior position of the mica schists.

The Mica Schist and Gneiss.—The inference that these rocks were primal, was based largely upon their lithological similarity to many of the older crystalline schists. They were hence referred to the White Mountain, or the Rocky Mountain, series. But lithological similarities must invariably bend to higher statigraphical evidence. In Delaware the micaceous rocks overlie the limestone, and no readjustment of position can make the arrangement otherwise. They are, therefore, younger than the limestone, which, in its turn, is younger than the underlying Potsdam.

The Calciferous limestone can hardly be referred to any other position, and, invariably underlying the schists, the latter must begin somewhere in the Silurian, and, possibly, mount as high up as the Devonian.

THE CRETACEOUS.

Geographical Extent.—The Cretaceous of Delaware, a continuation of the same formation as developed in New Jersey, extends across the State as a northeast and southwest belt, with a breadth of 18, and a length of from 15 to 20 miles, covering a total area of about 250 square miles. The northern limit of the belt, laid down on the map, has already been traced out as marking the southern boundary of the Laurentian. The southern limit runs a little to the south of, and parallel with, Appoquinimink Creek, cutting through the centre of Noxontown mill-pond, and thence proceeds in a straight southeasterly direction.

Subdivisions.—The formation may be divided into a number ot subdivisions, based upon lithological grounds, the period ot sedimentation extending through the whole Cretaceous; *i. e.*, Lower, Middle and Upper, of the English geologists. The divisions can be best represented by the following table, which is also

II.

UPPER CRETACEOUS (Chalk).	Middle Marl Bed.	Yellow Sand.
		Shell Layer.
		Pure Green Sand.
	Indurated Marl Bed.	Indurated Marl.
		Red Sand.
	Lower Marl Bed.	Black Argillo-Micaceous Marl.
		Shell Marl.
		Cretoidal Marl.
MIDDLE CRETACEOUS (Upper Green Sand, Gault).	Sand Marl. . .	Sand and Clay Marls.
LOWER CRETACEOUS (Wealden?).	Plastic Clays. .	Red Clay.
		Fire-Clays and Sands.

constructed with a view of showing the relative thickness of each of the groups. In the classification the plastic clays have been placed in the Lower Cretaceous, and are probably the exact equivalent of the Wealden, while the marl deposits, ranging from the Lower to the Middle Beds, can, upon palæontological grounds, be referred with considerable confidence to the Upper Cretaceous, or Chalk. The Sand Marl formation can at best be placed in but an intermediate position, but is probably nearly akin to the marls, all of the fossils ever found within the sand marls of New Jersey having been the characteristic species of the marl beds proper.

Structure.—The different subdivisions of the Cretaceous form uniform beds, dipping at a low angle to the southeast. Having been successively deposited upon a gently sloping bed, they have remained in the same position, with no subsequent disturbance. The general direction of *strike* can be seen from the trend of the various belts. A line joining the point of contact between the Cretaceous, at Newark, with a similar point back of Newport, upon nearly the same level, ran N. 72° E., which course, being approximately parallel with the lines of the lower belts, may fairly represent the strike of the formation. The *dip* was determined with great accuracy at Summit Bridge, about midway of the width of the Cretaceous. At this place the canal excavation has reached a depth of 70 feet, and continues several miles to the westward, with gradually lowering banks. Upon both sides of this wide cutting, the marl outcrops as a well-defined layer, and as any number of lines in the direction of the dip can be obtained, the amount of pitch can be accurately determined. As the transit could always be placed upon either bank in front of the escarpment of marl, and the other side could be easily seen, the operation of determining the difference in level between the two outcrops, on a line running S. 30° E., was not difficult. This difference in level, combined with the angle of depression, as determined by the vernier, would give the data for ascertaining the distance between the outcrops, the latter of which varied from 300 to 400 feet. The results of the observations give a dip of 45 feet to the mile.

PLASTIC CLAYS.

This formation is the thickest member of the Cretaceous. Its southern line begins a few miles south of New Castle, and extends in a southeasterly direction to just below Red Lion, crossing the railroad between Porter's and Kirkwood, and cutting the State line two miles north of Chesapeake City. Although of so much importance, it is, owing to the great thickness of the overlying gravels, rarely exposed, and even when more favorable opportunities are offered, but a few feet of the characteristic Red Clay appear above the surface. The formation is divided into the uppermost Red Clays, and the lowermost White Clays, of which the former is the deposit commonly exposed.

Red Clay.—This is a highly plastic clay, of a vermilion-red color, remarkably free from grit, and cutting with great smoothness. It is identical with the red terra-cotta clays of Perth Amboy, N. J., and may prove to be their equal in quality. The Red Clay forms uniform beds, with which are sometimes interstratified thin seams of fire-clay, making a total thickness of at least 50 feet. *White Clays.*—The series of white clays and sands lying beneath the stratum of red, reach to a great depth below the surface, and have not yet been wholly penetrated by the deepest boring made. The outcrop is upon the lowest ground, of which the only locality discovered lay a little to the south of New Castle, on the river shore. Here the white clay outcrops for a depth of from 10 to 15 feet, giving the following section:

1. Sandy fire-clay, . . .	3 feet.
2. Mottled clay, ...	3 feet.
3. A very pure fat fire-clay at water-level.	

The lowermost clay of this section is of an unusually fine quality, and has in past years been worked below water-level, and shipped to Trenton potteries. From this exposure we are enabled to see that the White Clay series, outcropping as it does at water-level, covered by a red stratum, and again by some 30 feet of gravel, is entirely out of the reach of study; yet the presumption that it does lie deeply buried is beyond controversy. Our only means of studying the White Clay series is by means of borings, which are very rare, and in no cases have accurate records of the deposits passed through been preserved. We only know that the borings yielded alternate layers of white clays and sands to a depth of 200 feet. We therefore judge that this series presents strong analogies to the white clays of New Jersey.

SAND MARL.

The belt of sand marl runs from the river course to the south of New Castle, gradually tapering in breadth as the Maryland boundary line is reached. The southern limit of the belt, starting at Delaware City, cuts the north corner of St. George's, and keeps about a mile above the canal for the remaining distance across the State. It may be described as a yellow sand, of a greenish tinge, comprising a yellow siliceous sand mixed with some green sand and a variable proportion of argillaceous matter. No data are at hand for determining its thickness, except the imperfect method of using width of outcrop and angle of dip, according to which we find the sand marl stratum to have a depth of 90 feet.

MARL BEDS.

The marl beds cover a comparatively small area in the State, and are practically limited to that division of New Castle county called St. George's Hundred.

The first important outcrops of green sand occur along the Delaware and Chesapeake Canal, the channel of which cuts deep into the formation. Its northern limit, as determined by old marl pits, runs approximately parallel with the canal, keeping a distance of from a quarter of a mile to a mile. From this line the marl extends southward to another boundary parallel with, and about one mile south of, Appoquinimink Creek, where it gives place to the Tertiary clays.

Subdivisions.—The divisions of the green sand formation are found, with two exceptions, to correspond with those made by the New Jersey Survey. In the first place, what is called by Professor Cook the Upper Marl bed, is in Delaware, entirely absent, and in the second place, the so-called *Red sand* is either entirely absent, or represented, as in the eastern part of the State, by a much thinner stratum than is found in New Jersey. This scanty development of the *Red sand* is, however, compensated for by a greater thickness of the *Indurated green marl*, which, in Delaware, becomes the prominent parting layer between the middle and lower marl beds. The chronological chart of the Cretaceous (II), will show the divisions of the marl beds as found in the State.

LOWER MARL BED.

This stratum, which extends as a narrow belt on each side of the canal, is found to outcrop along the entire length of the same, rising about a foot above the surface of the water, and, farther west, to a height of 20 feet. The several subdivisions of the lower marl will be treated in the order of their age.

Cretoidal Marl.—This lowest layer is a tough, bluish black marl, which, upon drying, turns to a lighter ashen or earthen color, when it is found to be made of a large amount of green sand, siliceous sand and argillaceous matter. The solid particles are coated with chalky carbonate of lime, which, under the microscope, appears as a fine white powder of a granular character, but often light and flocculent.

Shell Layer.—The cretoidal marl is always found beneath a layer of shells or shell marl, having a thickness of about 3 feet. In fact, the shells are usually mixed with a greater or less quantity of the black earthy marl having the characters of the cretoidal variety. The shells are usually the characteristic species of the New Jersey equivalents, the most abundant being the clumsy *Exogyra costata* with *Pychnodonta vesicularis* and *Ostrea larva.*

Black Argillaceous and Micaceous Marl.—This layer, overlying the shells, in its lower part possesses somewhat the characters of the *cretoidal marl.* To the west of the Delaware railroad, however, it rises well out of the water of the canal, and assumes a distinctly argillaceous nature, becoming a black micaceous clay. It also shows an entire absence of calcareous matter, and possesses a decidedly styptic taste, due to the large quantity of sulphate of iron in the percolating waters. This argillaceous marl, when examined in the dry state by a glass, is found to be composed of minute sharp glassy particles of quartz, coated with a grayish dust, and associated with a few green sand particles of unusual fineness, together with a considerable quantity of minute scales of muscovite.

Thickness.—Fortunately we have sufficient evidence for measuring accurately the thickness of the lower marl bed. The belt has an average breadth of 1½ miles, which, with a dip of 40 feet to the mile, would give a thickness of 60 feet for the stratum. At Summit Bridge, the black marl outcrops to a height of 42 to 47 feet. Calling it 40, and adding this to 15 feet of marl in Higgin's pit, on much lower ground between St. George's and Delaware City, we get a total of 55 feet. Since the 15 feet excavation at the latter place failed to entirely penetrate the marl, we may call 60 feet a safe estimate for the thickness of the lower marl bed. Of this total, more than one-half is represented by the argillo-micaceous layer, and the remainder by the thin shell layer, and the lowest cretoidal marl. There is one reason why the thickness of the lower marl stratum, as developed at Summit Bridge, should be employed in a calculation of the thickness, rather than the smaller figures obtained farther to the east or west. Summit Bridge is on the *dividing ridge.* From this meridional line, the land slopes to the east and west. The marl, therefore, offers a diminishing thickness of outcrop as the river is approached, owing to the erosion of the upper argillo-micaceous stratum, which, in the neighborhood of St. George's, and thence to Delaware City, has been thinned down to a thickness of only a few feet. It is for this reason that the upper portion of the lower marl bed is so extensively developed at the western end of the belt, while the lower portion of the same formation is confined to the eastern portion of the belt. Since the upper argillo-micaceous stratum is a poor, and even objectionable, material for fertilizing purposes, while the contrary may be said of the lower cretoidal variety, the locality for marl diggings must lie east of the railroad bridge.

INDURATED MARL BED.

The northern limit of this belt, which is also the southern limit of the lower marl bed, starts near the mouth of Scott's run, and thence keeps parallel with the canal to the railroad, when it begins slightly to diverge, cutting the headwaters of the northern branch of the Bohemia River. The southern limit of the belt can only be approximately outlined, but as can best be determined runs from Port Penn through the headwaters of Drawyer's Creek, and crosses the Maryland line four miles below the head of Bohemia River. The indurated marl stratum is divided into two layers, the lower red sand, and the upper indurated marl.

Red Sand.—The formation which has been called the indurated marl bed is the equivalent of the red sands of the New Jersey geologists, it being, in both cases, the prominent parting layer between the lower and middle marl. Along the south side of the canal, between the railroad bridge and St. George's, a soft reddish yellow sand of uniform character rests upon a stratum of black marl. It is developed to a considerable thickness in the neighborhood of the latter town, and is characterized by the numerous particles of green sand contained in it. The thickness could not, however, be accurately determined, running as it does, indistinctly into the overlying gravels. West of the railroad, the deposit thins out entirely, and does not again appear. Along the ravine made by Scott's Run the red sand has been found lying upon the shell marl, running to the south into a black decomposed green sand. Notwithstanding the deposit of red sand, which outcrops along the south shore of the canal, the shell marl is dug by several parties on a strip along the same side, and for this reason, I have extended the southern limit of the lower marl belt slightly to the south of the southern shore of the canal.

Considering the foregoing facts, the writer with some trouble that cannot well be removed, has referred the reddish yellow sand stratum to the red sand of Prof. Cook. This red sand occupies a narrow strip along the south side of the canal, to the east of the railroad, and runs to the south beneath the overlying stratum of decomposed marl, by which nearly the whole area of the bed as previously marked out, is covered. From this we see that the true red sand, which is so extensively developed in New Jersey has a less thickness in Delaware, but is replaced by the indurated marl, which in New Jersey is found more thickly exposed, but occupying the same stratigraphical position above the red sand.

Indurated Green Sand.—This marl attracts from the observer more attention than any other, coming to the surface as it does in numerous localities, and having been extensively worked for its pre-eminent qualities as a fertilizer.

Already in a state of partial decomposition, the decay rapidly progresses by the removal of the potash, and the oxidation of the ferous salt of iron, or its direct solution by carbonated water. Generally speaking, the marl in the bed is of a black, loamy nature which, when dry, assumes a brownish or grayish tinge. It is made of a variable quantity of green sand, with a large proportion of siliceous sand. In some places the marl is found to contain a large amount of argillaceous matter, while again it is extremely clean and dry. It differs entirely from the lower marl, by containing no carbonate of lime in the pulverent state; but in certain places the deposit abounds in shells, which renders it comparable with the shell marl of the former formation.

Examined with a glass, the grains of indurated marl prove of a brownish color, and very rough and irregular, apparently the effect of weathering. The grains can easily be crushed by the finger-nail, thus exposing the internal green color. The granules are coated with a layer of brown oxide of iron, within which shell exists the unchanged nucleus of glauconite.

The *Indurated Marl*, unless finely pulverized, has a lumpy tendency, caused by numerous grains of green sand cemented by the brown oxide of iron. In fact, the marl has, at certain points, been almost entirely changed to brown oxide of iron, while in other cases, seams of the latter penetrate the mass of the green sand. Prof. Cook is of the opinion that the red sand of New Jersey is due to the decomposition of green sand, whereby the soluble salts have been carried away, leaving the insoluble siliceous sand and red oxide of iron. We may, therefore, regard the belt, which in New Jersey is called the red sand, and in Delaware the indurated marl, as a true marl belt in a greater or less degree of decomposition; and while a slightly indurated green sand may entirely differ mineralogically from a red siliceous sand, the difference is after all only one of degree of decomposition.

MIDDLE MARL BED.

This belt crosses the State with a uniform breadth of three and a half miles, the northern line running from Port Penn, a little north of Drawyer's creek, and crossing the State line four miles south of the Bohemia River. The southern line crosses the centre of Noxontown mill-pond, keeping parallel with and a little south of Appoquinimink creek. The middle marl bed (see II) is divided into three very distinct layers: (1) A lowermost pure green sand; (2) an intermediate layer of friable shells, and (3) an upper yellow or reddish yellow sand. The characters of these several strata will be considered as follows :—

Green Sand Layer.—This lowermost subdivision of the middle marl bed occupies the main width of the belt to the north of Appoquinimink Creek, and exhibits its principal exposures along Drawyer's Creek and Silver Run, where its characters may be well studied. It differs entirely from any of the foregoing varieties, in that it is entirely free from calcareous matter, and shows none of the general induration so characteristic of the previous formation. On the contrary, it is a very dry, pure green sand, which varies in color from a deep bluish to a yellowish green, the latter shade being due to a considerable admixture of siliceous sand.

The extreme dryness of this marl, compared with the preceding varieties, is owing to the complete absence of argillaceous matter. The grains, when examined, are smooth and well rounded, and although frequently so soft as to be easily crushed by the nail, show no evidence of chemical decomposition.

Shell Layer.—This intermediate, well-defined layer, is best exposed at the head of Noxontown mill-pond, and along the south side of Appoquinimink Creek. In thickness it varies from 3 to 10 feet, being entirely made up of white friable shells, tightly packed together, the most common of which are *Terebratula fragalis* and *T. Harlani*, with *Pychnodonta vesicularis.*

Very often the upper part of the shell layer has lost its carbonate of lime, which is replaced by brown oxide of iron. At the head of Noxontown mill-pond, the white shell layer, of which the upper part is ferruginous, rises 5 to 6 feet out of the water, capped by a yellow sand marl.

Yellow Sand.—This is the uppermost layer of the Middle Marl Bed, and is always found associated with and overlying the shells. It may be described as a yellowish or reddish sand, containing a small and variable proportion of glauconite, the latter often becoming so predominant as to give the deposit a decidedly greenish tinge.

DIORITIC TRAP.

Three miles to the south of Newark, Delaware, Iron Hill rises from the Cretaceous plane, the one conspicuous object for 10 miles or more. Running in a generally northwest and southeast direction, it has a length of over 3 miles, a width varying from 1 mile to 1½, and a height of 225 feet. The flanks and summits of this hill are covered with boulders of diorite and cellular quartz. On the south side, about half way up, is seen the outcrop of a bedded mass of serpentine rock, with a strike following the trend of the hill. An examination of the loose fragments of green rock lying upon the surface showed them to be composed of a number of indefinite chloritic and serpentine materials in a state of partial decomposition. As the greenish fragments were also observed to run into unchanged trap, occurring as huge outcropping boulders, the proof appeared conclusive that the serpentine rock had been due to the alteration of the hornblende in the dioritic trap. Following the hill in its northwest course, we find the same rock crossing the railroad, along the cutting of which the nature of the dike is revealed.

Here we first pass some 200 feet of a soft greenish clay, which rises as walls 20 feet high. Fragments of the serpentine rock, on the surface above the railroad cutting, showed it running into unchanged diorite. Lying next to the serpentine rock was 50 feet or more of both compact and cellular quartz, standing upon edge, and striking to the northwest. It was completely impregnated with minute specks and octahedrons of magnetite, which exhibited their decomposition by numerous minute cells filled with iron oxide. The cellular quartz, associated indiscriminately with the compact, was literally honeycombed, the great cells being partially filled with ochrey powder. West of the quartz occurred a thinner development of the serpentine, offering the same features as before. With these facts, we are led to regard the exposure before us as a highly changed dioritic dike, in the centre of which is a huge mass of ferruginous jaspery quartz, from which we interpret the structure of the whole hill. Attaining the summit, we find several large pits worked for iron ore. One of them, wrought by George Whitaker, has walls of soft greenish serpentine earth rising some 40 feet, in which are imbedded boulders and fragments of cellular ferruginous quartz and ironstone, together with a considerable admixture of ochrey powder and granular limonite. The economic value of the workings consists in washing the serpentine earth, and extracting the limonitic materials. Near the wash-house the yellowish green rock is seen to outcrop with a strike to the northwest. Several of the pits on the hill offer much the same features, while some of them contain a greater abundance of the boulders of cellular quartz. The method of formation of the crusts of iron-stone may be determined by an examination of the numerous quartzose boulders. It consists in the segregation of iron oxide as tortuous veins within the substance of the rock, set free by the complete disintegration of the latter; while the powdery and granular limonite has resulted from an oxidation of the magnetite which so completely impregnates the jaspery quartz. Associated with the boulders of trap, are certain foreign materials belonging to the drift. Imbedded within the serpentine earth of Whitaker's pit, are several large decomposed boulders of granite. Upon the summit of the hill, a large boulder of dark limestone was also found, besides various other materials belonging to the boulder drift so universally scattered over the State.